Development of Portable Rocket Stove and Performance Evaluation

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Abstract - *Due to structure error and the incompleteness of combustion reaction, the traditional cook stove cannot utilize the generated heat more than 8-10%. This results in higher usage of fuel and increases environmental pollution and health hazard. Improved Stoves increase the efficiency of fuel consumption and to an extent reduce pollution for indoor cooking environments. This research work was an effort to manufacture rocket stove i.e. improved stove which would be both economically affordable and environmentally sound. The stove was manufactured in such a way so it would be user-friendly. Results obtained from the performance tests of the designed rocket stove were satisfactory. The thermal efficiency was found 30.52% from the performance test of the stove. The concentration of CO was ranged from 4.58 mg/m^3 to 14.89 mg/m^3.*

Key Words: **Cookstove, Thermal Efficiency, Rocket Stove**

1. INTRODUCTION

Bangladesh is one of the most densely populated nations with the majority of poor people. According to the last Household Income and Expenditure Survey (2010), 17.6% of the populations are below the lower poverty line. In rural areas, where more than 70% of the population lives, 35% is below the upper benchmark and 21% fall even below the lower regional poverty lines (BDT 1192-1495). [1]

The per capita income of Bangladesh has touched US$1190. An average family of the country consists of 4.5 household members. The average per capita income level of consumers below the upper poverty line is BDT1271 per month, for those below the lower poverty line it is only BDT 1102.84 per month on the national level. [1]

1.1 Energy Situation

The total population of Bangladesh is 158.5 million. About 66% of the total populations reside in rural areas. It is estimated that 59.6% of the population have access to the electricity grid. It is mentioned by BBS (Bangladesh Bureau of Statistics) that 90% of this population has access to electricity in urban areas and only 42% have access in rural areas. The electricity supply does not meet the demand of this huge population. [2]

Moreover, only 6% of the entire population, primarily in urban areas, has the privilege of natural gas [1]. Biomass fuels, commonly as wood, leaves, twigs, straws, cow dung and agricultural residues are collected from the indigenous environment. These have become a traded commodity as the cooking fuel as access to local biomass is getting more difficult than ever.

From Table-1, it is seen that biomass as cooking fuel is about 86% in 2011, whereas the other fuels include only 14%.

Table-1: Source of Cooking Fuels (in %) [1]

Fuel Type	2011	2004	1991
Wood	34.8	31.76	44.27
Straw, Leaves, Dried Cow Dung	51.2	55.91	-
Kerosene	1.0	1.79	0.57
Gas/LPG	12.6	9.09	2.36
Electricity	0.4	0.76	0.88
Bio-gas	0.1	-	-

The natural growth of forests, as well as afforestation measures, is too low to meet the consumption of the population due to the inefficient burning of biomass for cooking purposes and high population growths, putting pressure on the economic situation of biomass-purchasing households. Poor rural households have to spend a significant amount of time on biomass collection. Wastage of biomass is depriving the soil of nutrients, resulting in unsustainable low levels of organic matter in the soil.

1.2 Cooking Scenario

Using biomass as cooking fuel, inefficient and poorly ventilated clay stoves produce fine particles, polycyclic aromatic hydrocarbons, carbon monoxide, dioxins and other carcinogens. Housewives are exposed to high levels of these toxins between three and seven hours a day. Research revealed that this indoor air pollution (IAP) not only affects the cook, but also affects other family members such as children. The World Health Organization (WHO) estimated that more than 46,000 women and children die each year as a direct result of exposure to indoor air pollution, while much more suffer from respiratory diseases, tuberculosis, asthma, cardiovascular disease, eye diseases, and lung cancer. 70% of the victims of indoor air pollution are children under five. [3]

Again, each day thousands of work hours are spent collecting wood, usually by women and children. By using less wood, some of this time could be spent more usefully. In towns, where wood is purchased, saved money could be spent for the improvement of living standards.

For efficient combustion of the fuel at a high temperature by ensuring a good air draft into the fire, controlled use of fuel, complete combustion of volatiles, and efficient use of the resultant heat, rocket stove or improved fuel stove has been used for cooking purpose.

It is important to note that rocket stoves are designed for populations around the world who depend on biomass for their cooking fuel. The rocket stove was originally developed for cooking, where a relatively small amount of continuous heat is applied to the bottom and sides of a cooking pot. These stoves can be constructed from brick, recycled steel cans, or steel sheet metal, or can be purchased.

Although rocket stoves are found more commonly in third world countries where wood fuel sources are scarce, they have seen in recent years increased use in developed countries, such as the United States. Some are small for portability, with insulation inside a double-walled design and a chamber for partial biomass gasification and additional mixing to increase heat production and provide a cleaner, more complete burn. The advantage of rocket stoves is that less fuel is needed, such as wood and dry weeds, to be able to cook a whole meal with it, keeping the air cleaner with less hydrocarbons and carbon monoxide.

1.3 Objective of the Study

Rocket stoves are an attempt to address the negative health and environmental issues related to the traditional cooking methods. The traditional cook stove cannot utilize the generated heat more than 8-10% due to structure error and incompleteness of combustion reaction. This causes high usage of fuel and this contributes to environmental pollution and health hazard. Improved Stoves increase the efficiency of fuel consumption and reduce pollution released into indoor cooking environments. These stoves designs are constructed with metal housing and insulating materials enclosing the fire. The intention of performing this project was to build a rocket stove that would be able to improve heat transfer and fuel combustion, resulting in an economically efficient clean burning wood stove.

The rocket stove was designed with the help of theoretical knowledge. After completing the certain design, the theoretical model was constructed from sheet metal and insulation. Then Water Boiling Test (WBT) was done to evaluate the performance of the built stove.

2. THEORY

Improved rocket stove was designed to increase fuel efficiency, reduce harmful emissions associated with combustion of wood as fuel. This was successfully done through a combination of increased combustion efficiency and heat transfer [4]. Improving the combustion efficiency is necessary to reduce smoke and harmful emissions that damage health. Improving heat transfer efficiency can significantly reduce fuel use. Fire is naturally good at its job, but pots are not as good at capturing heat because they are inefficient heat exchangers. In order to reduce emissions and fuel use, it is necessary to first clean up the fire and then force as much energy into the pot as possible. Both of these functions can be accomplished in a well-engineered cooking stove.

For better combustion efficiency the following should be checked [5]

1. Good drafting into the fire.
2. Good insulation around the fire to help it burn hotter. A hotter fire burns up more of the combustible gases and produces less smoke.
3. Avoiding heavy, cold materials like earth and sand to be used around the combustion chamber.
4. Lifting up the burning sticks off the ground so that air can scrape under the sticks and through the charcoal.
5. Heating only the burning part of the wood because the non-burning wood tends to make smoke.
6. The cold air limitation while entering the fire by using as small an opening as possible. Small openings into the fire also force the cook to use less wood, which can be burnt more efficiently.
7. A certain amount of excess air is necessary for complete combustion. Preheating the air helps to maintain clean combustion.

For better fuel efficiency the following way should be concerned [5]

1. The increase of the temperature of the gas/flame contacting the pot, having the hot air scrapes against both the bottom and sides of the pot in a narrow channel, using a pot skirt.
2. The increase of the speed of the hot flue gases that scrape against the pot. The fast gases punch through a boundary layer of still air that keeps slower moving gases from scraping against the surface of the pot (or griddle.) Air is a poor heat transfer medium. It takes a lot of hot air to bring heat to the pot.
3. Use of metal rather than clay pots because metal conducts heat better than clay.

4. Use of the wide pots with large diameters. Using a wide pot creates more surface area to increase the transfer of heat.

When cooking begins, the walls of the stove are cold. After certain times they warm up at a rate which are determined by their mass and specific heat. Light-weight walls have a low thermal inertia and warm quickly. Thick, heavy walls, warm more slowly. Heat loss from the combustion chamber is determined by how quickly these walls warm and subsequently how much heat the wall loses from its outside surface. This is shown clearly in Fig-1, where the thicker the wall the more slowly it warms.

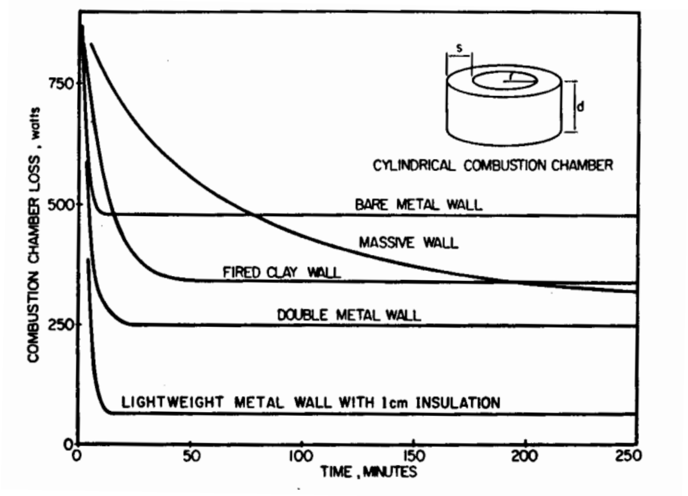

Fig-1: Heat loss into and through combustion chamber walls of varying material as a function of time elapsed since starting the fire. [4]

Although a thick wall of dense high specific heat material may have slightly lower heat loss than a thinner wall after several hours, it takes many hours more for the eventual lower heat loss of the thick wall to compensate for its much greater absorption of heat to warm up to this state. Thus, it is always preferable to make the solid (non-insulator) portion of the wall as thin and light as possible.

Additionally, the use of lightweight insulators such as fiberglass or double wall construction can dramatically lower heat loss.

Materials such as sand-clay or concrete, which have a high specific heat and density, and which must be formed in thick sections to be sufficiently strong to support a pot or resist the fire, should, therefore be avoided.

In radiative heat transfer, a view factor is the proportion of the radiation which leaves the surface that strikes the surface. In a complex 'scene' there can be any number of different objects, which can be divided in turn into even more surfaces and surface segments.

From a disc of radius R_1 to a parallel disc of radius R_2 at separation H with $r_1 = R_1/H$ and $r_2 = R_2/H$.

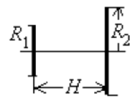

Fig-2: Estimation for View Factor

View factor, $F=(x-y)/2$,
With $x= 1+ (1/r_1^2) + (r_2^2/ r_1^2)$
and $y = \sqrt{(x^2-4r_2^2/r_1^2)}$ [6], [7]

2.1 Design Principles of Rocket Stove

Any type of intermittently fed wood burning stove can first be designed by locals to meet their needs and then finished by adapting these following principles. [8]

1. Insulation around the fire using lightweight, heat-resistant materials.

2. Heating and burning of the tips of the sticks as they enter into the fire.

3. Creation of high and low heat by sticks which are pushed into the fire.

4. Maintenance of a good fast draft through the burning fuel.

5. Too little draft being pulled into the fire will result in smoke and excess charcoal.

6. Maintenance of constant cross-sectional area. This is achieved by the same size of the opening into the fire, the size of the spaces within the stove through which hot air flows, and the chimney.

7. Using of grate under the fire.

8. Insulation of the heat flow path.

9. Maximization of heat transfer to the pot with properly sized gaps.

Establishing the same cross-sectional area everywhere in a cooking stove ensures sufficient draft for good combustion while resulting in channel gaps that increase heat transfer efficiency. This means that the opening into the combustion chamber, the combustion chamber, the air gap under the pot or griddle, and the chimney are the same size (equal number of square centimeters) while having different shapes. Slowing down the draft hurts both combustion and heat transfer efficiency to the pot.

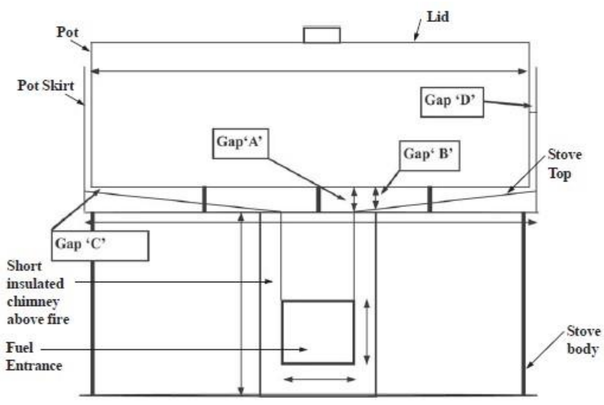

Fig-3: A Typical Stove [8]

Here,
The distance between the pot and the inner perimeter of the combustion chamber:
Gap A = Area/(Inner perimeter of combustion chamber)

Distance between the pot and the outer edge of the combustion chamber:
Gap B = Area/Circumference

The Gap under the outer edge of the pot and the stove body:
Gap C = Area/(Circumference of pot)

Gap between the sides of the pot and the stove body:
Gap D = Gap C * 0.75

Some typical cross sectional area for square combustion chambers [8] are given below

Table-2: For 12 cm × 12 cm Square Combustion Chamber

Pot Size (cm)	20	30	40	50
Gap A	3	3	3	3
Gap B	2.5	2.5	2.5	2.5
Gap C	2.3	1.5	1.1	0.9
Gap D	2.1	1.5	1.1	0.9

Table-3: For 14 cm × 14 cm Square Combustion Chamber

Pot Size (cm)	20	30	40	50
Gap A	3.5	3.5	3.5	3.5
Gap B	3.1	3.1	3.1	3.1
Gap C	3.1	2.1	1.6	1.2
Gap D	2.7	2.1	5	1.2

Table-4: For 16 cm × 16 cm Square Combustion Chamber

Pot Size (cm)	20	30	40	50
Gap A	NA	4	4	4
Gap B	NA	3.7	3.7	3.7
Gap C	NA	2.7	2	1.6
Gap D	NA	2.5	1.9	1.6

Table-5: For 18 cm × 18 cm Square Combustion Chamber

Pot Size (cm)	20	30	40	50
Gap A	NA	4.5	4.5	4.5
Gap B	NA	4.3	4.3	4.3
Gap C	NA	3.4	2.6	2.1
Gap D	NA	3.1	2	4.2

3. EXPERIMENTAL

3.1 Design Basis

The design of rocket stove was performed depending upon the major parameter which was the amount of water to be vaporized at a certain interval of time. While designing the rocket stove, lower heat loss, and environmental impact was also concerned.

3.2 Construction of Rocket Stove

While manufacturing of the cook stove, some common parameters were concerned. By considering all of these parameters, height, length, width of cook stove was taken.

3.2.1 Combustion Chamber Height

The height of the combustion chamber, H= A+P+L [4]
Here,
A = Air hole height in cm
P = Height from the air hole to pot bottom = 0.4 × pot diameter (for cylindrical pot)
L = Distance between the pot bottom and the pot mouth.
From this formula, the combustion chamber height was taken to be 8 inches.
The height of the support below the combustion chamber was 8 inches from the ground.
So the total height of rocket stove was 16 inches from the ground.

3.2.2 Pot Mouth

Pot mouth is the hole where the pot sits on. There were two pot mouths. Each mouth was 8×8 square inches in area. Therefore, 8-inch to 10-inch pot can easily be set here.

3.2.3 Grate

A metallic rectangular shaped grate was used in the rocket stove. It was placed just above the stocking or primary air inlet hole. The grate was 7.5 × 7.5 square inches in area. Some slits made of the metallic rod were incorporated in the grate. This grate acted as fuel bed and allowed better mixing of combustion air and fuel.

3.2.4 Wall Thickness of Combustion Chamber

The wall of the combustion chamber was made of steel. The thickness of the wall was 1 mm or 0.04 inches. The steel wall made the stove hot quickly.

3.2.5 Stoking Hole

The stoking hole was rectangular in shape. It was 6 inches in length and 4 inches in height. At the primary hole, there was auxiliary equipment named fuel holder. It held the woods and helped the cook to work easily.

3.2.6 Primary Air Inlet

A primary air inlet was placed on stove models at the bottom to provide excess air for drafting and better combustion. The hole size was smaller than the stoking hole. The hole was 6 inches in length and 2 inches in height. There was a tray for charcoal at the bottom of the stove.

3.2.7 Rectangular Support Box

A rectangular metallic box made of steel was around the main body of the stove. This box was 21 inches in length, 10 inches in width and 17 inches in height. The wall thickness of the box was 1 mm or 0.04 inches. The space between the main body and the box was filled up with rock wool which acted as the insulator.

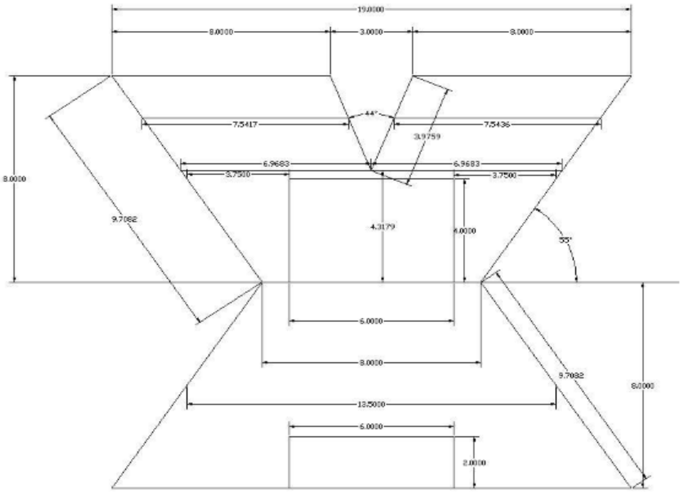

Fig-4: Design of the Main Part of Rocket Stove (measurement in inches)

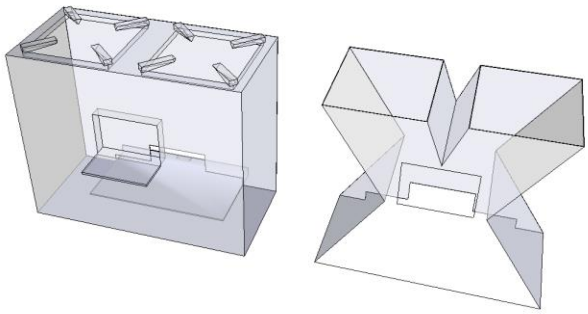

Fig-5: Three Dimensional View of Rocket Stove from Front

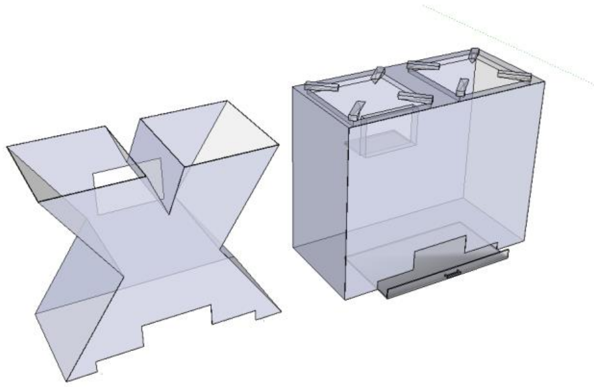

Fig-6: Three Dimensional View of Rocket Stove from Back

3.3 Performance Evaluation Test

Modified version of Water Boiling Test (WBT), version 4.2.3 [9] and indoor air pollution measurement by Gasteq tube method were followed to evaluate the performances of the cook stove.

3.3.1 Water Boiling Test

This test provides the stove designer with reliable information about the performance of wood burning stove models. The test consists of three phases that determine the stove's ability. They are:

1. To bring water to a boil from a cold start;
2. To bring water to a boil when the stove is hot;
3. To maintain the water at simmering temperatures.

It is used to evaluate a series of stoves as they are being developed. The test cannot be used to compare stoves from different places because the different pots and wood used change the results.

The test is a simplified version of the University of California Berkeley (UCB)/Shell Foundation revision of the 1985 VITA International Standard Water Boiling Test. The wood used for boiling and simmering and the time to boil are found by simple subtraction. All calculation can be done by hand in the field.

3.3.1.1 Equipment Used for Water Boiling Test

Following equipment were used for WBT—

- Scale of at least 6 kg capacity and 1 gram accuracy
- Heat resistant pad to protect scale
- Digital thermometer,
- Timer
- Testing pot(s)
- Wood fixture for holding thermometer probe in water
- Small shovel/spatula to remove charcoal from stove
- Tongs for handling charcoal
- Dust pan for transferring charcoal
- Metal tray to hold charcoal for weighing
- Heat resistant gloves
- 3 bundles of air-dried fuel wood. One, used for simmering, weighs around 5 kg. The other two bundles, used for cold and hot start boiling, weigh about 2 kg each

At the beginning of the test the following procedure should be concerned

1. The air temperature was recorded.

2. The weight of commonly used pot without the lid was recorded. As two pots were used, the weight of each pot was recorded.

3. The weight of container for charcoal was recorded.
4. Bundles of fuelwood were weighed for beginning the experiment. Sticks of wood were roughly the same size for all tests.
5. Approximate dimensions of the fuelwood were measured.

3.3.1.2 High Power (Cold Start) Phase

The stove should be at room temperature.

1. Each pot was filled with 5 L of clean water. The weight of pot(s) plus the water was weighed.

2. Using the wooden fixtures, a thermometer probe was placed in each pot so that water temperature might be measured in the center, 5 cm from the bottom. A digital thermometer was used. Water temperatures were recorded.

3. The weight of the starting materials was recorded. Always the same amount and material were used.

4. The fire using the wood from bundle was started.

5. Once the fire has caught, the timer was started.

6. When the water in the first pot reaches the local boiling temperature as shown by the digital thermometer, the following was done rapidly:

   a. The time at which the water in pot reaches the local boiling point of water was recorded. The water temperature for other pots was recorded as well.
   b. All wood from the stove was removed and the flames were put out. All loose charcoal was knocked from the ends of the wood into the tray for weighing charcoal.
   c. The unburned wood from the stove was weighed together with the remaining wood from the pre-weighed bundle.
   d. Each pot, with its water, was weighed and recorded.
   e. All the charcoal from the stove was removed and placed it with the charcoal that was knocked off the sticks and weighted.

3.3.1.3 High Power (Hot Start) Phase

1. The pots were refilled with 5 L of fresh cold water and weighed and temperatures were measured.

2. The fire using kindling and wood from the bundle was started. The time when the fire started was recorded.

3. The time at which the first pot reaches the local boiling point was recorded.
4. After reaching the boiling temperature, the following was done rapidly:
   a. The time at which the water in pot reaches the local boiling point of water was recorded. The water temperature for other pots was recorded as well.

b. All wood from the stove was removed and the flames were put out. All loose charcoal was knocked from the ends of the wood into the tray for weighing charcoal.

c. The unburned wood from the stove was weighted together with the remaining wood from the pre-weighed bundle.

d. Each pot, with its water was weighted and recorded.

e. Without pause, the simmering test was proceeded.

3.3.1.4 Low Power (Simmering) Test

This phase is designed to test the ability of the stove to simmer water using as little wood as possible. The start of Low Power test:

1. The weight of the bundle of fuel was recorded.

2. The weight of the pot (with water) from high power phase was measured. The temperature was also recorded.

3. The fire was rekindled using kindling and wood from the weighed bundle and the start time when the fire started was recorded. The water was kept as close to 30C below the boiling point as possible.

4. The temperature of the water was recorded.

5. For the next 45 minutes, the fire was maintained at a level that keeps the water temperature as close as possible to 30C below the boiling point.

6. After 45 minutes rapidly the following was done:

   a. The finishing time of the test was recorded.

   b. The temperature of the water at end of test was recorded.

   c. All wood from the stove was removed and knocked any loose charcoal into the charcoal weighing pan. The remaining wood was measured, including the unused wood from the preweighed bundle. The weight of wood was recorded.

   d. The pot with the remaining water was measured.

   e. All remaining charcoal from the stove was measured and weighed it (including charcoal, which was knocked off the sticks). The weight of pan plus charcoal was recorded.

This completes the full water boiling test. The full test should be done at least three times for each stove for accurate results.

3.3.2 Indoor Air Pollution Measurement

Indoor air pollution was also measured by measuring the amount of CO released during cooking. Tedlar Bags were used for indoor air sampling. Then by Gasket Tube method, CO was measured. The volume of the room was 16 m^3. There were two windows and each of them was 0.27 m^2 in area. The door was 1.395 m^2 in area which was 2.6 times larger than the two windows. The door and the windows all were fully opened during both water boiling and CO measurement test.

4. RESULTS AND DISCUSSIONS

An improved fuel stove, that is, rocket stove was designed and different parameters for performance evaluation were determined from water boiling test (WBT). Three sets of water boiling test were performed by using wood as fuel. Cold start high power, hot start high power and simmering were performed for each test. After the completion of the tests, results were compared with all cold start, hot start and simmering respectively. Carbon-monoxide concentration was also calculated.

4.1 Local Boiling Point and Time Required for Boiling

From the water boiling test, the local boiling point of water was found 99.7 ^oC. The time required for boiling was different for cold start and hot start. The average time for boiling was about 35 min and 32 min for cold start and hot start respectively. In the case of the hot start, the stove was already hot, so less time was required for boiling to start.

4.2 Burning Rate

Burning rate is a measurement of the rate of fuel consumption for water to boil. The average burning rate for cold start, hot start, and simmering was found to be 22, 24 and 18 g/min respectively.

4.3 Thermal Efficiency

The main parameter for evaluating the performance of the designed rocket stove was thermal efficiency. Thermal efficiency was found 31.64%, 29.40% and 32.80% during cold start, hot start and simmering phase. So the overall thermal efficiency was 30.52%.

4.4 Specific Fuel Consumption

Specific fuel consumption indicates the amount of fuel required to vaporize a certain amount of water usually 1 liter water. Specific fuel consumption was 85, 81 and 117 g/liter for cold start, hot start and simmering respectively. As for hot run, fuel consumption was less because the stove remained warmer from preceding test run.

4.5 Firepower

Firepower is the ratio of fuel energy consumed by the stove per unit time. It was found to be 6.5, 7.1 and 5.4 KW for cold start, hot start and simmering respectively.

4.6 Turndown Ratio

Turndown ratio indicates the operability of a stove with low power input. From the entire test run for low power phase, the turndown ratio was found to be 1. Stoves with a higher turndown ratio are likely to use less fuel during a real cooking task, which involves bringing food to a boil and then cooking it at a simmer for an extended period of time.

Below are the summarized test results for cold start, hot start and simmering consisting important parameters from water boiling testing.

Table-6: Calculated Results for all Cold Start

Cold Start	Units	Test 1	Test 2	Test 3	Average	St Dev	COV %
Time to boil Pot 1	min	30	36	40	35.33	5.0	14.2
Burning rate	g/min	27	22	18	22	4.8	21.5
Thermal efficiency	%	24	33	37	31.64	6.67	21.1
Specific fuel consumption	g/liter	93	85	77	85	7.8	9.1
Firepower	watts	8,031	6,437	5,221	6,563.1	1,408.8	21.5

Table-7: Temperature Corrected Values for all Cold Start

Cold Start	Units	Test 1	Test 2	Test 3	Average	St Dev	COV %
Time to boil Pot 1	min	33	37	42	37	4.3	11.7
Specific fuel consumption	g/liter	102	87	81	90	11.0	12.3
Specific energy consumption	kJ/liter	1,810	1,545	1,428	1594	195.8	12.3

Table-8: Calculated Results for all Hot Start

Hot Start	Units	Test 1	Test 2	Test 3	Average	St Dev	COV %
Time to boil Pot 1	min	26	31	38	31.667	6.0	19.03
Burning rate	g/min	26	26	20	24	3.2	13.17
Thermal efficiency	%	29	30	29	29.40	0.64	2.18
Specific fuel consumption	g/liter	75	86	82	81	5.5	6.77
Firepower	watts	7,615	7,671	6,023	7103	935.5	13.17

Table-9: Temperature Corrected Values for all Hot Start

Hot Start	Units	Test 1	Test 2	Test 3	Average	St Dev	COV %
Time to boil Pot 1	min	28	32	40	33	5.7	17.19
Specific fuel consumption	g/liter	82	89	85	85	3.3	3.86
Specific energy consumption	kJ/liter	1,455	1,571	1,513	1513	58.4	3.86

Table-10: Calculated Results for all Simmering

Simmering	Units	Test 1	Test 2	Test 3	Average	St Dev	COV %
Time to boil Pot 1	min	30	36	40	35.33	5.0	14.2
Burning rate	g/min	20	19	15	18	3	16.55
Thermal efficiency	%	27	31	40	32.80	6.63	20.22
Specific fuel consumption	g/liter	135	123	92	117	22.3	19.12
Firepower	watts	6,051	5,739	4374	5388	891.9	16.55

Table-11: Temperature Corrected Values for all Simmering

Simmering	Units	Test 1	Test 2	Test 3	Average	St Dev	COV %
Specific energy consumption	kJ/liter	2,400	2,180	1631	2070	395.9	19.12
Turndown ratio	g/liter	---	1.33	1.12	1.19	1.0	0.1

4.7 Concentration of CO

According to the Bangladesh Gazettes (2005), the tolerance limit for CO is 10 mg/m^3 and 40 mg/m^3 for 8 hrs and 1 hr average respectively. In the test runs, each start took less an hour. From the following values, it is obvious that the lower values and higher values are less than 40 mg/m^3. So CO concentration in our test runs did not cross the tolerance limit.

Table-12: CO Concentration

CO	Unit	Lower Value	Higher Value
Cold Start	mg/m3	4.58	5.73
Hot Start	mg/m3	5.15	6.30
Simmering	mg/m3	13.74	14.89

5. CONCLUSIONS

In Bangladesh, the rural people depend on biomass as cooking fuel. Rocket stove is much more improved and efficient than tradition mud stoves. During rainy season, people can easily move these stoves according to their convenience. Our research was just an effort to manufacture rocket stove which would be both economically affordable and environmentally sound. Also, it was kept in mind to design the stove as user friendly. The result obtained for the rocket stove designed for three performance test runs was satisfactory and proved the validity of the structure.
The average thermal efficiency was found 30.52% during the performance test of the stove. The efficiency result could have been more consistent if the operator was a bit more cautious in stoking. Time required for boiling water was more or less satisfactory. The indoor pollution was also within tolerance limit. All these data indicate that the project work was successfully completed. This research work can be further improved if more experimental work is done in future.

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